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Water Chemistry and Fish Population Status of Ten Lakes in Southern New Brunswick: 1988 Survey

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WATER CHEMISTRY AND FISH POPULATION STATUS OF TEN LAKES IN SOUTHERN NEW BRUNSWICK: 1988 SURVEY

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ABSTRACT

Martin-Robichaud, D. J., and R. H. Peterson. 1990. Water chemistry and fish population status of ten lakes in southern New Brunswick: 1988 survey. Can. Tech. Rep. Fish. Aquat. Sci. 1727: iii + 24 p.

Ten lakes in southern New Brunswick were surveyed again in 1988 to continue the monitoring program initiated in 1978. Temperature and precipitation patterns in 1988 were intermediate to those in 1978 and 1983, resulting in concentrations of ions intermediate to those of two previous surveys. Spring pH levels were higher in 1988 than 1983 because there was less rainfall in the spring of 1988. As a result, the temporal increase in alkalinity deficit (A_D) observed in 1983 was not as evident in 1988.

A background level of 34 $\mu eq.L^{-1}$ of SO_4^{2-} was estimated for the 10 lakes, which is lower than the 40 $\mu eq.L^{-1}$ determined for 1983.

Observations of the fish species present in these lakes in 1988 indicate that there has been no major change in the fish population status of these lakes since 1978.

RÉSUMÉ

Martin-Robichaud, D. J., and R. H. Peterson. 1990. Water chemistry and fish population status of ten lakes in southern New Brunswick: 1988 survey. Can. Tech. Rep. Fish. Aquat. Sci. 1727: iii + 24 p.

Dix lacs du sud du Nouveau-Brunswick ont été recensés encore une fois en 1988 afin de poursuivre le programme de contrôle amorcé en 1978. En 1988, la configuration des températures et des précipitations se situait à un niveau intermédiaire entre celles de 1978 et de 1983, entraînant ainsi des concentrations ioniques intermédiaires par rapport à celles des deux relevés précédents. Les niveaux de pH du printemps étaient plus élevés en 1988 qu'en 1983 puisqu'il y avait eu moins de chutes de pluie au printemps 1988. Par conséquent, l'augmentation temporelle du déficit en alcalinité (A_D) observée en 1983 n'était pas aussi manifeste en 1988.

Pour les dix lacs, on a évalué un niveau de fond de 34 $\mu éq.L^{-1}$ d'ions sulfate (SO_4^{2-}), ce qui est plus bas que le niveau de 40 $\mu éq.L^{-1}$ établi pour 1983.

Les observations des espèces de poissons présentes dans ces lacs en 1988 révèlent qu'il n'y a eu aucun changement majeur dans la situation des populations de poissons dans ces lacs depuis 1978.

INTRODUCTION

The effects of acidic precipitation resulting from industrial emissions on freshwater ecosystems have been a serious environmental problem for years. To evaluate the impact of long-range transport of atmospheric pollutants on surface waters and thus biota, long-term monitoring is required. Because of recent evidence that sulfuric emissions may be declining (Driscoll et al. 1989), investigations should continue to monitor chemical and biotic changes and thereby provide information necessary for predicting responses of aquatic systems to changes in deposition. Headwater lakes are among the most sensitive receptors of acidic precipitation and the resulting changes in water chemistry may have deleterious effects on fish populations (Wright 1983).

Since 1978, 10 lakes in New Brunswick have been monitored every 5 yr to provide data on physico-chemical parameters, and every 10 yr to identify resident fish populations. This report discusses and compares the water chemistry and fish communities studied during the 1988 sampling season (May-October) with results obtained in 1978 and 1983 (Peterson 1980; Peterson and Martin-Robichaud 1984). Lake characteristics, location and selection criteria were previously discussed by Peterson (1980).

METHODS

Methodological consistency is necessary for accurate comparisons; therefore, the methodology employed during this survey was identical to that used in 1983 with minor modifications made to the 1978 methods (Peterson and Martin-Robichaud 1984). Sulphate concentrations determined by both ion chromatography (IC) and by the methyl thymol blue procedure will be reported. Ion chromatography is now accepted as the standard technique for sulphate analysis (Kerekes et al. 1984; Jeffries et al. 1986) due to humic acid interference encountered with colored waters (>30 Hazen units or >6 $mg.L^{-1}$ dissolved organic carbon (DOC)) when using the colorimetric method. However, yearly comparisons were done using values obtained colorimetrically because this method was originally used in the 1978 analysis.

Fish were sampled three times from each lake throughout the summer. Sites were beach seined in May and October and electrofished in August. Due to manpower limitations, no gillnets were set in 1988. Beach seining techniques were identical to those of 1978 (Peterson and Martin-Robichaud 1982). Again, Mud Lake was not seined due to unsuitable substrate and shoreline. Electrofishing was conducted on the same shoreline segments that were seined to ensure adequate sampling, especially in lakes with substrate less suitable for beach seining. The maximum depth electrofished was approximately 2 ft. The total number of fish sampled through the summer was combined to provide a qualitative observation of existing fish populations within each lake.

RESULTS AND DISCUSSION

CLIMATIC FACTORS

Cumulative degree-days and rainfall from April to October in 1988 were intermediate to those of 1978 and 1983, although monthly mean temperatures were not consistently intermediate (Fig. 1, 2). These climatic factors can significantly affect water chemistry by evaporation or dilution processes. The cumulative rainfall vectors during the sampling period exhibited the same south-southwest influence that was evident during the other years (Fig. 3).

In 1988, all the lakes reached higher maximum surface water temperatures (usually in August) and lower October temperatures than the two other surveys (Fig. 4), although 1988 air temperatures were intermediate to those of 1978 and 1983. Daily surface water temperature can fluctuate significantly, depending on the ambient air temperature. The three sampling days in August were about 3°C hotter than the monthly average. The month of October in 1988 was cooler than it was in the other years.

pH

The mean pH of the lakes ranged from 5.8 (Robin Hood Lake) to 7.4 (Mud Lake) (Table 1). Lake pH during the sampling period of 1988 did not usually deviate greatly from values recorded in 1978 and 1983, although the pH of Robin Hood Lake rose about 0.4 units higher in August than in the other years (Fig. 5). The pH of Robin Hood Lake also dropped from an August high of 6.2 to 5.5 in October, which is

contrary to the usual trend of increasing through the summer. Lower pH levels are usually detected in spring and early summer due to the acidic spring runoff of snow and ice and heavier precipitation influence. The rise in pH during the summer may be caused by increased primary production, lower rainfall inputs and greater groundwater influence. Comparing the pH curves of the 3 yr in Fig. 5, it is evident that pH is more variable in spring and early summer, and more stable in late summer. Knight and Tims (1987) determined that the precipitation pH of New Brunswick in 1986 ranged from 4.4-4.9. The pH of New Brunswick precipitation averaged 4.3-4.5 in 1988 (Tims, New Brunswick Department of Municipal Affairs and Environment, Fredericton, N.B., pers. commun.).

It may be noted here that surface pH measurements in mid-summer may not be indicative of pH levels present at greater depths. Chisholm Lake, a shallow lake with a large submerged vegetation biomass, was found to have a lower pH at 1 m depth than at the surface (Mr. H. Hoar, 18 Vernon Ave., Riverview, N.B., E1B 3Y1, pers. commun.). This was further confirmed in July when the surface pH was 6.0, compared to 5.0 at 1 m. Since exhaustive aeration of the 1-m sample raised the pH to 6.0, we conclude that CO_2 liberated by decomposition of sedimented plant material was responsible. This pH stratification with depth did not exist in May, probably due to lower lake temperature.

CONDUCTIVITY AND SEA SALT INFLUENCE

Surface water conductivities in 1988 were generally similar to those measured in 1978 and 1983 (Fig. 6). Mud Lake had higher conductivity levels during 1988. This increased conductivity and correspondingly higher ionic concentrations detected in 1988 may have been the result of road salt input, although this conclusion is still debatable because all ion concentrations were higher except for K.

The mean Na and Cl concentrations in the 10 lakes were intermediate to those measured in 1983 (Fig. 7) and 1978. Higher water temperatures probably resulted in more concentrated Na than detected in 1983. Chloride levels also seemed to rise slightly which was not observed during the other summers. The peak in Na:Cl ratios observed in 1983 did not occur in 1988. Instead, there was a gradual increase in this ratio from May to October (Fig. 7).

Concentrations of K in the 10 New Brunswick lakes were higher in 1988 (Table 2) than in 1983 but not as high as 1978 levels (Peterson 1980; Peterson and Martin-Robichaud 1984). The low levels of 1983 were likely the result of dilution from greater precipitation. K concentrations of 1978 were higher than 1988 because it was a relatively dry summer.

Oceanic salts significantly affect the ionic concentration of maritime lakes. This is well illustrated by the higher Na and Cl levels (Fig. 8, 9) and conductivities of lakes close to the ocean such as Wheaton Lake. Brydges and Summers (1989) consider any lake receiving precipitation with a Na concentration >4 $\mu eq.L^{-1}$ significantly influenced by sea spray carried in on regional weather systems. To evaluate regional water chemistry characteristics in relation to anthropogenic pollutants and geological interactions, it is necessary to factor out the marine ionic component. From all ionic concentrations, we have corrected for the sea-salt component by utilizing the technique of subtracting the ion concentration determined from the equivalence ratio to the Cl concentration in seawater, assuming all Cl measured in the lake is derived from oceanic sources (Henriksen 1982). Chloride was used as the sea-salt tracer to correlate with 1978 and 1983 calculations. It has recently been postulated that heavy deposition of sea salts may cause temporary acidification of the soil water and runoff (Wright et al. 1988), but these cation exchange reactions cannot explain regional acidification (Mason and Seip 1985; Norton et al. 1989).

ACID NEUTRALIZING CAPACITY

The sum of the basic cations is closely correlated with the original alkalinity (A_0) of surface waters due to their association with bicarbonate. Henriksen (1982) proposed the following equation to calculate A_0 in natural oligotrophic surface waters: $A_0 = -14 + 0.93(Ca + Mg)$. Only non-oceanic sources of Ca and Mg should be considered since seaspray can contribute a significant amount into lake waters, particularly Mg (15-70% for these lakes; Peterson (1980); Table 3, 4). The primary source of non-marine Ca is from soil weathering and ion exchange processes.

Alkalinity is considered a measure of the acid neutralizing capacity (ANC) of the bicarbonate buffer system and is frequently used to quantify the acid base status of surface waters. Lakes are frequently classified acidic if ANC values are less than zero. Acidification is also quantified by decreases in ANC. ANC is a measure of the net strong base in a solution as determined by the Gran procedure. Sullivan et al. (1989) found that measured and calculated ANC values usually agree except for low ANC waters with high levels of monomeric Al and also waters with high DOC (>800 µmol C.L^{-1}). The lakes studied here do not fit these criteria; therefore, further correction factors were unnecessary.

Any reduction in bicarbonate levels below the sum of the base cations should indicate a loss of ANC due to acidification. Most of the study lakes show some loss of ANC, since they lie below the line of Henriksen's equation (Fig. 10). The distance a point lies below this line is a measure of the alkalinity deficit or ANC loss. This may also be calculated by subtracting the present alkalinity, A_T, from A_O (Table 5). Schindler (1986) considers water column alkalinity an unsuitable indicator of lake ANC, because the alkalinity generated by various biological processes (such as sulphate and nitrate reduction) increases when the concentrations of SO_4^{2-} and NO_3^- increase.

Henriksen (1979) devised an empirical "acidification" indicator to visualize possible acidified and nonacidified lakes. This relationship assumes that the lakes are buffered primarily by a calcium carbonate system. These 10 lakes fit these criteria and, since all lie below the curve, are considered nonacidified (Fig. 11). A few of the lakes, Creasey Lake in particular, tended to shift closer to the curve in 1983 and Mosquito Lake lies on the curve in 1988, indicating that further bicarbonate depletion could render this lake acidified as delineated by this indicator. Mosquito Lake shifted closer to the curve in 1988 because of an increase in the Ca^{2+} concentration, not due to a decline in pH.

Production of ANC is a complex process involving weathering, ion exchange reactions, biological buffering by sulfate and nitrate reductions, and primary production. Therefore, it is not surprising to find that there are significant temporal variations in many of the parameters investigated during acidification studies (Schindler 1986; Wright 1983). The ANC of lakes can vary greatly because many terrestrial and within-lake processes contribute ANC in various degrees to surface waters (Jeffries et al. 1986). Spring rains and snowmelt runoff tend to reduce pH, Ca and Mg concentrations and the alkalinity deficit (Peterson and Martin-Robichaud 1984).

Sulfate loading results in a corresponding decrease in ANC due to acid neutralization processes; therefore, when SO_4^{2-} levels increase, so should the alkalinity deficit. The regression of alkalinity deficit (A_D) on non-oceanic SO_4^{2-} is $A_D = 31.93 - 0.938\ SO_4^{2-}$ (r^2=0.90) (Fig. 12). From this equation, the "background" SO_4^{2-} level at zero A_D is 34 µeq.L^{-1}. This is lower than the 40 µeq.L^{-1} determined in 1983 for the same lakes (Peterson and Martin-Robichaud 1984). Henriksen (1982) proposed that Norwegian lakes have a "background" SO_4^{2-} of 10-20 µeq.L^{-1} and realized that there would be significant differences between countries.

There is the possibility that some SO_4^{2-} is entering the system as $CaSO_4$ or $MgSO_4$ from gypsum weathering. Therefore, calculations of "original" alkalinity levels would be biased due to Ca and Mg inputs not associated with bicarbonate. Inferences would then indicate that lake acidification had progressed further than it actually had. Peterson et al. (1986) considered this possibility but found no correlation of [Ca and Mg] with SO_4^{2-} for New Brunswick lakes, although it appeared that N.B. lakes had higher SO_4^{2-} and higher [Ca and Mg] levels than Nova Scotia lakes.

For the purpose of predicting lake acidification, Henriksen (1982) constructed a nomogram relating sulfate loading or precipitation pH to original alkalinity levels determined by the relationship to Ca and Mg concentrations. On the basis of this nomogram, all the lakes surveyed can be classified as bicarbonate lakes (pH > 5.3) (Fig. 13). The fish population status of such lakes should have intact stable populations if other factors such as fishing pressure did not exist. The background SO_4^{2-}, 34 µeq.L^{-1}, was subtracted from the SO_4^{2-} measured by IC. The survey of 69 N.B. lakes completed in 1981 and 1982 by Peterson et al. (1986) classified 50 lakes bicarbonate, 16 transitional and 3 acidic on the basis of the above criteria. The turbidimetric measurements of SO_4^{2-} were considered 15 µeq.L^{-1} too high so

this was subtracted. Kelso et al. (1986) classified 15% of the same 69 lakes acidic using Henriksen's nomogram but stated that the SO_4^{2-} levels seemed excessive, probably because there was no correction for the overestimation of the turbidimetric technique or for lake "background" sulfate levels.

Measurements of seasonal variation in [Ca and Mg] and [SO_4^{2-}] are similar to 1983 measurements in that lower levels were detected in the spring and increased throughout the summer (Fig. 14). Sulfate concentrations tended to decrease in late summer but this was not observed in 1983. Alkalinity deficits did not show a consistent increase throughout the summer as detected in 1983 (Table 5). The hypothesis generated by Peterson and Martin-Robichaud (1984) to explain these seasonal trends suggested that spring runoff and precipitation with high concentrations of H^+ but low levels of HCO_3^- resulted in low pH during spring. Lakes exhibiting these characteristics would be temporarily considered "precipitation-dominated lakes" since they obtain little ANC from the drainage basin (Eilers et al. 1983; Bradt et al. 1986). If precipitation SO_4^{2-} loads were substantial, then SO_4^{2-} concentrations would also increase during spring (Schoen 1986). This observation agrees with our findings: in 1983, higher precipitation resulted in higher SO_4^{2-} concentrations but 1988 spring levels of SO_4^{2-} were lower than in 1983 and increased gradually throughout the summer. Considering the normalized SO_4^{2-} values to allow visualization of temporal trends, it is only the May and June levels that are below 1983 values, verifying the reduced precipitation influence in the spring of 1988.

Greater groundwater inputs throughout the summer which have higher Ca^{2+}, Mg^{2+} and HCO_3^- concentrations buffered the H^+, thereby increasing the pH and the alkalinity deficit. The higher pH detected during the spring of 1988 resulted in less HCO_3^- buffering required to neutralize acidity acquired during this time and, therefore, increasing alkalinity deficits would not be as obvious. Further monitoring of these parameters will possibly verify the existence of seasonal trends and precipitation influences.

Figure 15 illustrates the relationship between calculated "original" alkalinity, actual alkalinity and SO_4^{2-} load. At zero alkalinity, the histogram depicts the "background" concentration of approximately 30 $\mu eq.L^{-1}$ determined previously.

IONIC BALANCE

To maintain electrochemical neutrality, the sum of all cations must equal the sum of anions (Fig. 16). This principle allows a suitable confirmation of ionic levels detected; any significant deviation would indicate an analytical error. Sulfate results obtained colorimetrically were used to balance ions as this seems to compensate for the omission of organic anions from the summation due to the inherent interference in the analytical technique. The mean ionic percent difference (I%D) (Brydges and Summers 1989) for the monthly ion balances for each lake never exceeded 4% (Table 6).

DOC AND SILICA

Most lakes in this survey can be considered "clear" water lakes (<10-15 Hazen units) (Table 7). Mill and Robin Hood Lakes are slightly more colored than measured in 1983: 28 and 20 versus 22 and 18, respectively. The relationship between the monthly pH, [Mg and Ca] and color for all 3 yr combined for two of the most dilute lakes studied, Robin Hood and Chisholm, results in the following regressions:

$$pH = 6.54 - 0.009(Mg \& Ca) - 0.021(color),$$
$$r^2 = 0.69, n = 12 \text{ and}$$

$$pH = 5.30 + 0.014(Mg \& Ca) - 0.014(color),$$
$$r^2 = 0.86, n = 12, \text{ respectively.}$$

Levels of DOC (Table 8) were similar to those measured in 1983. Mud Lake has the most DOC owing to its shallow productive character. DOC concentrations increase throughout the summer, peaking in September, then declining (Fig. 14).

The concentration of silica in surface waters has been used as an "index of weathering" but, like Driscoll et al. (1989), we found no correlation of silica concentration with base cation levels (Table 9, 3). The highest levels of Si were found in Mill and Robin Hood Lakes.

FISH POPULATIONS

When comparing the 1978 and 1988 fish surveys, there were 47 incidences when fish species caught in 1978 were not captured in 1988 when both gillnetting and beach seining results were compared to the beach seining and electrofishing samples of 1988. Omitting the gillnetting samples of 1978 reduced the number of incidences to 10 (Table 10). Gillnetting conducted in 1978 used 1/2-1 1/4 in^2 (1.27-3.18 cm^2) mesh which stretched to 2 1/2 in^2 (6.35 cm^2) and, therefore, caught many of the larger midwater species such as brown bullhead, Atlantic salmon and chain pickerel. These species were not captured either year by beach seining or electrofishing. Still, considering only the 1978 beach seining samples, there were 11 incidences when species caught in 1988 were not captured in 1978, although this does not imply that they were not present previously.

The fish communities of these lakes can be classified on the basis of the fish assemblages determined by Peterson and Martin-Robichaud (1989). Using multivariate statistical techniques, we classified 145 lakes in New Brunswick and Nova Scotia on the basis of five fish community assemblages. The two lake physico-chemical parameters most important in distinguishing the fish communities were lake area and pH. Lakes with the smallest surface area and, therefore, the least diverse habitat to support a wide variety of species contained mainly brook trout. Chisholm and Stein Lakes have the smallest surface areas (8 and 5 ha, respectively) of the 10 lakes surveyed and support a brook trout and 9-spine stickleback assemblage, although Stein Lake also contains introduced smallmouth bass. Mosquito, Creasey and Kerr Lakes tend to have intermediate surface areas (91, 19 and 77 ha, respectively) and fit the brook trout/white sucker assemblage, although smaller species which would not be caught with gillnets were also present. Bolton, Mill and Wheaton Lakes, having larger surface areas (310, 150, 110 ha, respectively), contain multispecies assemblages composed of white sucker, yellow and white perch, brown bullhead, smallmouth bass and numerous smaller species. Mud and Robin Hood Lakes contain a variety of species, although it is unclear to which fish community assemblage they belong. The 1981 and 1982 fish population surveys conducted by Peterson et al. (1986) on 145 New Brunswick and Nova Scotia lakes also classified four of the lakes studied in this survey. Mosquito, Kerr, Creasey and Bolton Lakes were all grouped into the same assemblages based on the results of multivariate statistical programs as we have allocated them in this report. Lake area is the only parameter required for the classification of these lakes, because pH is responsible for separating the yellow perch only fish assemblage found in more acidic waters.

Future monitoring and evaluation of acid precipitation effects on surface water chemistry will probably focus attention on the concentration of base cations in the water systems. Over the long term, soils become leached of their base cations, resulting in significant alkalinity and pH changes in the water column (Reuss et al. 1987). Lake chemistry should be monitored closely to investigate the effect of reductions in SO_4^{2-} emissions which may slowly materialize. Driscoll et al. (1989) hypothesized that with decreased precipitation acidity there is a reduced input of base cations from weathering, that less is leached from the soil because of reduced acidic inputs, and that the base cation pools are depleted from previous acidic runoff. The result of this may be that in some surface waters base cations tend to be decreasing and acidification progressing, although there is reduced SO_4^{2-} loading (Dillon et al. 1987).

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Table 1. Surface pH levels for the various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	7.0	7.3	7.1	7.5	7.7	7.6	7.4
Bolton	6.6	6.6	6.9	7.0	7.1	7.1	6.9
Chisholm	6.1	6.0	6.0	6.1	6.3	6.3	6.1
Robin Hood	5.8	5.6	6.1	6.2	5.7	5.5	5.8
Mosquito	6.2	5.6	6.0	6.0	5.8	5.9	5.9
Creasey	6.6	6.4	6.3	6.6	6.5	6.7	6.5
Kerr	6.9	6.5	6.4	6.9	6.8	6.8	6.7
Mill	7.2	6.5	7.0	7.1	7.1	7.1	7.0
Stein	7.1	6.7	6.7	7.2	6.7	6.9	6.9
Wheaton	7.0	7.0	7.2	7.1	7.3	7.4	7.2

Table 2. Potassium concentrations ($\mu eq.L^{-1}$) in surface waters of various lakes, 1988. Potassium calculated to be of sea salt origin shown in parentheses. Total concentrations are the sum of the two figures.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	8.0(1.03)	19.4(1.06)	19.0(1.18)	18.2(1.24)	18.5(1.24)	18.9(1.29)	17.0
Bolton	6.2(0.44)	6.4(0.53)	6.1(0.53)	6.7(0.53)	6.8(0.55)	6.7(0.53)	6.5
Chisholm	5.6(0.97)	6.1(1.06)	5.5(1.12)	6.1(1.12)	6.1(1.06)	4.9(1.18)	5.7
Robin Hood	3.7(0.91)	3.9(0.97)	3.6(0.97)	4.1(1.03)	4.9(0.97)	4.6(0.97)	4.1
Mosquito	5.5(1.12)	8.6(1.12)	5.8(1.12)	6.0(1.24)	7.1(1.12)	6.5(1.24)	6.6
Creasey	4.2(1.44)	4.8(1.29)	4.8(1.29)	5.3(1.35)	5.3(1.29)	4.3(1.35)	4.8
Kerr	6.5(1.24)	6.7(1.18)	9.0(1.24)	6.6(1.29)	6.5(1.18)	6.2(1.24)	5.9
Mill	6.7(1.65)	8.1(1.65)	7.2(1.77)	7.7(1.82)	7.7(1.77)	8.8(1.94)	7.7
Stein	2.7(1.39)	3.2(1.12)	2.6(1.18)	2.9(1.24)	1.6(1.18)	4.3(1.35)	2.9
Wheaton	2.2(5.04)	3.1(4.83)	3.0(4.88)	3.4(4.98)	3.4(5.04)	3.9(5.15)	3.2

Table 3. Calcium concentrations ($\mu eq.L^{-1}$) in surface waters of various lakes, 1988. Calcium calculated to be of sea salt origin shown in parentheses. Total concentrations are the sum of the two figures.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	362 (2.05)	427(2.13)	497(2.36)	532(2.47)	547 (2.47)	546 (2.58)	485
Bolton	129 (0.87)	134(1.06)	144(1.06)	134(1.06)	139 (1.18)	144 (1.06)	137
Chisholm	48 (1.94)	44(2.13)	45(2.24)	46(2.24)	53 (2.13)	68 (2.36)	51
Robin Hood	46 (1.82)	48(1.94)	53(1.94)	53(2.05)	58 (1.94)	58 (1.94)	53
Mosquito	38 (2.24)	41(2.24)	40(2.24)	39(2.47)	39 (2.24)	43 (2.47)	40
Creasey	77 (2.89)	77(2.58)	82(2.58)	82(2.70)	82 (2.58)	92 (2.70)	82
Kerr	108 (2.47)	103(2.36)	108(2.47)	102(2.58)	108 (2.36)	113 (2.47)	107
Mill	152 (3.31)	162(3.31)	176(3.53)	186(3.65)	181 (3.53)	181 (3.88)	173
Stein	147 (2.77)	138(2.24)	158(2.36)	158(2.47)	158 (2.36)	167 (2.70)	154
Wheaton	180(10.07)	190(9.65)	195(9.77)	190(9.96)	195(10.07)	200(10.30)	192

Table 4. Magnesium concentrations ($\mu eq.L^{-1}$) in surface waters of various lakes, 1988. Magnesium calculated to be of sea salt origin shown in parentheses. Total concentrations are the sum of the two figures.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	27.6(10.3)	33.8(10.6)	37.6(11.8)	38.6(12.4)	41.1(12.4)	39.0(12.9)	36.2
Bolton	31.0 (4.4)	34.2 (5.3)	32.6 (5.3)	32.6 (5.3)	33.6 (5.9)	33.4 (5.3)	32.9
Chisholm	11.7 (9.7)	14.1(10.6)	16.0(11.2)	16.8(11.2)	19.9(10.6)	21.9(11.8)	16.7
Robin Hood	11.5 (9.1)	10.9 (9.7)	11.7 (9.7)	11.1(10.3)	14.2 (9.7)	12.5 (9.7)	12.0
Mosquito	9.4(11.2)	8.8(11.2)	7.7(11.2)	6.5(12.4)	7.7(11.2)	5.7(12.4)	7.6
Creasey	18.5(14.4)	18.4(12.9)	20.8(12.9)	20.2(13.5)	21.7(12.9)	21.1(13.5)	20.1
Kerr	27.1(12.4)	27.7(11.8)	28.8(12.4)	27.4(12.9)	31.0(11.8)	29.6(12.4)	28.6
Mill	30.4(16.5)	34.5(16.5)	35.8(17.7)	42.7(18.2)	42.4(17.7)	41.5(19.4)	37.9
Stein	44.5(13.9)	46.4(11.2)	49.9(11.8)	51.8(12.4)	50.8(11.8)	52.3(13.5)	49.3
Wheaton	7.2(50.4)	11.0(48.3)	12.1(48.8)	13.6(49.8)	12.2(50.4)	11.9(51.8)	11.3

Table 5. Alkalinity deficits ($eq.L^{-1}$) as determined by the difference between the measured lake alkalinity (A_T) and the theoretical original lake alkalinity (A_0) predicted by the equation: $A_0 = -14 + 0.93(Ca^{2+} + Mg^{2+})$. A negative value indicates that the measured value is less than the theoretical.

	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	-41	-49	-64	-26	-33	-33	-41
Bolton	-35	-36	-47	-21	-33	-31	-34
Chisholm	-16	-8	-23	-21	-30	-34	-22
Robin Hood	-22	-15	-28	-4	-31	-24	-21
Mosquito	-12	-17	-13	-15	-18	-16	-15
Creasey	-39	-42	-46	-27	-37	-35	-38
Kerr	-52	-46	-50	-38	-45	-41	-45
Mill	-47	-47	-49	-23	-48	-35	-42
Stein	-57	-15	-58	-39	-62	-38	-45
Wheaton	-0.11	-7	-15	16	-0.7	19	2
Mean	-32	-28	-39	-20	-34	-27	
Normalized mean	1.1	0.93	1.3	0.67	1.1	0.90	

Table 6. The ionic percentage difference (I%D) of the cations and anions in the 10 New Brunswick lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	-	4.18	4.74	1.92	2.75	2.28	3.17
Bolton	5.23	2.95	7.38	0.044	3.08	2.08	3.46
Chisholm	2.23	3.07	3.77	1.42	4.23	0.72	2.57
Robin Hood	2.36	2.89	8.26	2.06	4.80	1.80	3.70
Mosquito	0.79	5.69	3.33	0.052	7.06	0.83	2.96
Creasey	0.45	3.25	3.21	1.79	0.22	1.58	1.75
Kerr	6.08	2.75	5.42	0.85	5.95	2.33	3.90
Mill	3.95	3.45	4.26	0.44	4.54	2.80	3.24
Stein	3.55	3.71	5.64	1.26	5.70	0.48	3.39
Wheaton	0.88	1.29	4.01	0.60	1.71	0.45	1.49

Table 7. Color (apparent; Hazen units) of water in the various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	10	5	5	5	5	5	6
Bolton	10	10	5	5	5	5	7
Chisholm	10	10	5	5	5	20	9
Robin Hood	35	20	10	5	25	25	20
Mosquito	5	5	<5	5	5	<5	5
Creasey	5	5	<5	<5	<5	<5	<5
Kerr	10	10	5	5	5	5	7
Mill	25	30	20	20	40	35	28
Stein	10	20	5	5	25	15	13
Wheaton	5	5	<5	<5	<5	<5	<5

Table 8. Concentration of dissolved organic carbon (mg/L) in the various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	4.1	5.3	5.2	6.6	6.6	6.8	5.8
Bolton	4.4	4.1	3.8	4.3	3.8	3.6	4.0
Chisholm	3.5	3.6	3.5	4.4	3.9	4.9	4.0
Robin Hood	4.8	5.1	3.7	4.1	5.4	4.8	4.7
Mosquito	2.7	2.7	2.1	2.4	2.3	2.3	2.4
Creasey	2.7	3.0	3.2	4.0	3.3	3.7	3.3
Kerr	3.2	4.1	4.0	4.1	3.9	3.9	3.9
Mill	3.9	4.5	4.5	5.6	6.1	5.2	5.0
Stein	3.7	5.1	4.6	5.2	6.6	5.1	5.1
Wheaton	3.2	3.6	3.2	3.5	3.3	3.1	3.3
Mean	3.6	4.1	3.8	4.4	4.5	4.3	
Normalized	0.87	0.99	0.92	1.07	1.09	1.04	

Table 9. Silica concentration ($\mu eq.L^{-1}$) in the various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	224	50	216	413	627	285	303
Bolton	375	245	148	142	228	171	218
Chisholm	137	26	16	64	171	142	93
Robin Hood	480	443	390	441	684	527	494
Mosquito	191	151	130	114	128	93	135
Creasey	191	141	121	142	285	185	178
Kerr	440	443	413	441	598	370	451
Mill	567	544	453	570	570	641	558
Stein	406	278	108	115	498	456	310
Wheaton	158	122	67	30	157	157	115

Table 10. Incidence of capture of fish species in 1988 and compared to species caught by beach seining in 1978.

Species	Mud	Bolton	Chisholm	Robin Hood	Mos-quito	Creasey	Kerr	Mill	Stein	Wheaton	Total
White sucker		1		3*				18			22
White perch		57								>100	>157
Yellow perch		10						37			47
American eel							1		4*	14	19
Brook trout			20		•			1*			21
Smallmouth bass								2			2
Pumpkinseed		•					4*	1*			5
Banded killifish	9*			45	10	370	8	255	266	40	994
Finescale dace				3*							9
Golden shiner											3
Blacknose dace							1*	2*			3
Blacknose shiner							32				32
N. redbelly dace					•	1*				•	1
Creek chub		11*									11
9-spine stick.			464	58	6	111	25	10		1	675
3-spine stick.								44			44
Pearl dace		2*									2
Common shiner		•					•				
Lake chub							•				
Rainbow smelt								•			
Fallfish		•		•							
TOTAL	9	81	484	109	16	482	71	370	270	215	2107

*Species caught in 1988 but not in 1978.
•Species caught in 1978 but not in 1988.

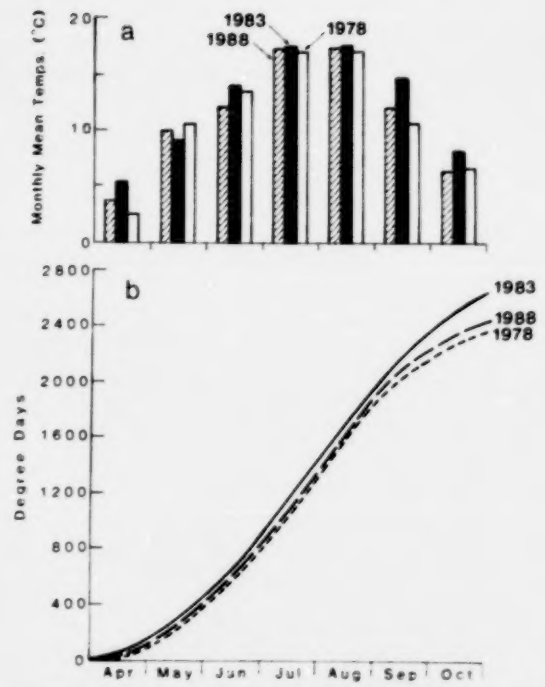

Fig. 1a. Monthly temperatures of 10 N.B. lakes from April-October for 1978, 1983 and 1988.
1b. Cumulative air degree-days from April-October for each of the three surveys.

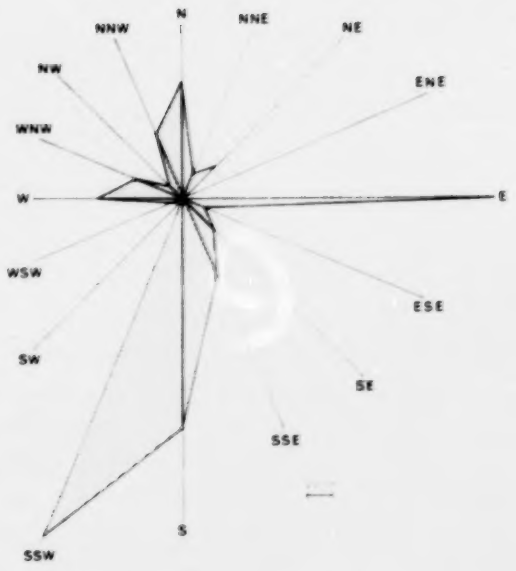

Fig. 3. Cumulative precipitation for 1988 originating from various compass sectors as derived from weather reports issued from the Saint John, N. B. weather station.

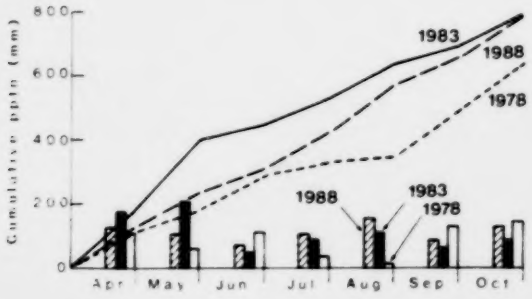

Fig. 2. Monthly and cumulative precipitation for 1978, 1983 and 1988. Data from weather reports issued from the Saint John, N. B. airport weather station.

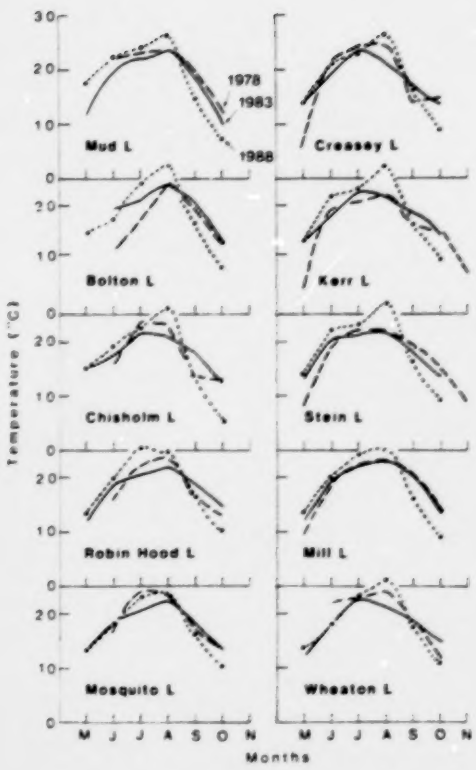

Fig. 4. Lake surface water temperatures for the 10 study lakes from April-October during 1978, 1983 and 1988. Lines fitted by eye.

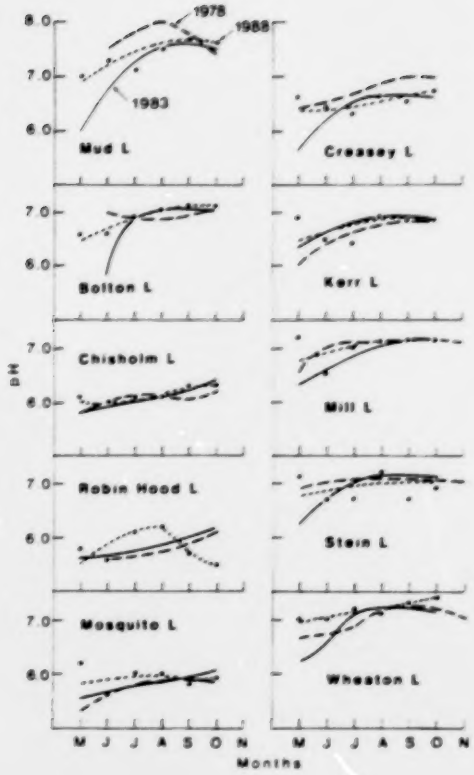

Fig. 5. Surface pH values for 10 lakes studied in 1978, 1983 and 1988. Lines fitted by eye.

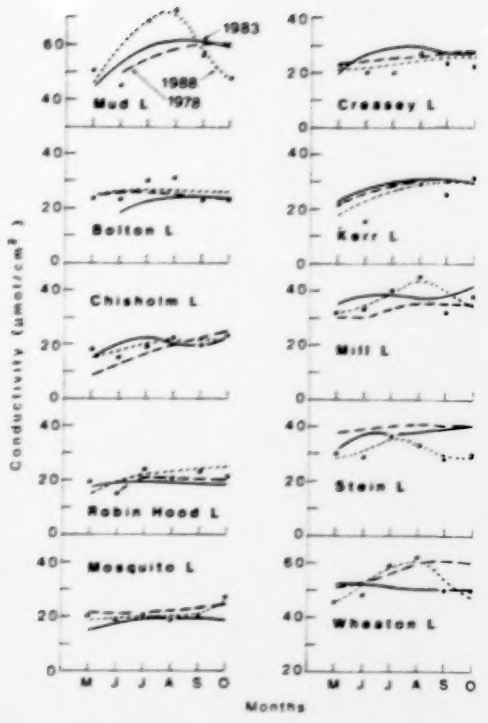

Fig. 6. Surface water conductivities for 10 lakes studied in 1978, 1983 and 1988. Lines fitted by eye.

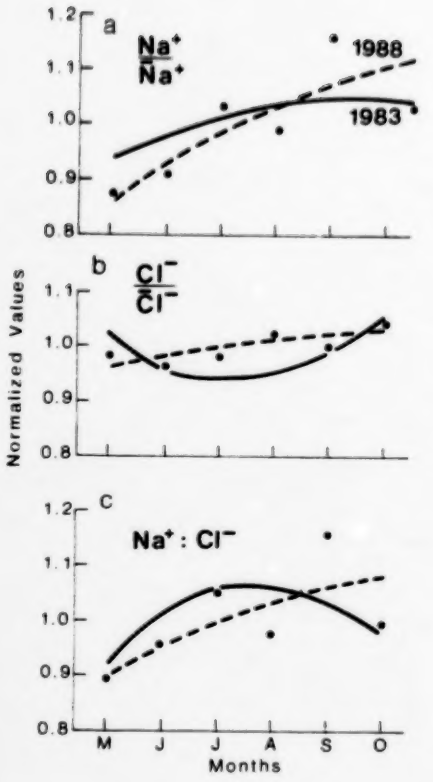

Fig. 7a. Normalized mean Na concentrations for the study lakes in 1983 and 1988.

7b. Normalized mean Cl concentrations for the study lakes in 1983 and 1988.

7c. Na:Cl ratios for normalized means from May-October. Points indicate 1988 values and lines fitted by eye.

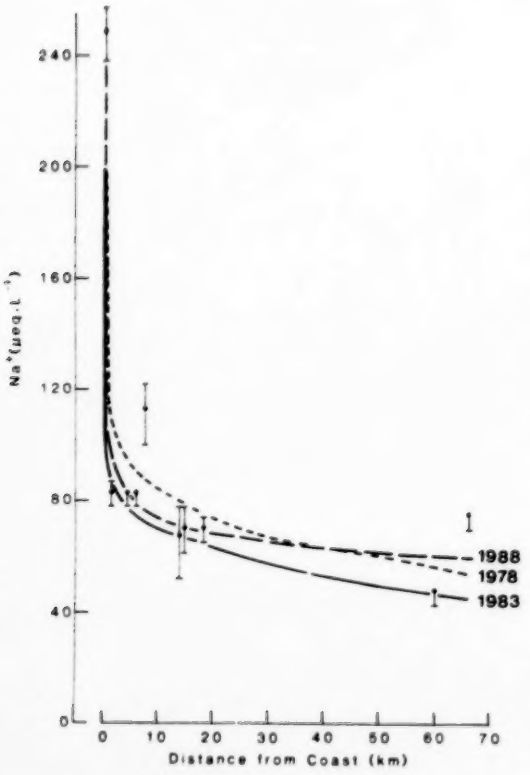

Fig. 8. Mean sodium concentrations in surface waters of 10 N.B. lakes in 1988, as related to distance from the coast compared to 1978 and 1983 concentrations.

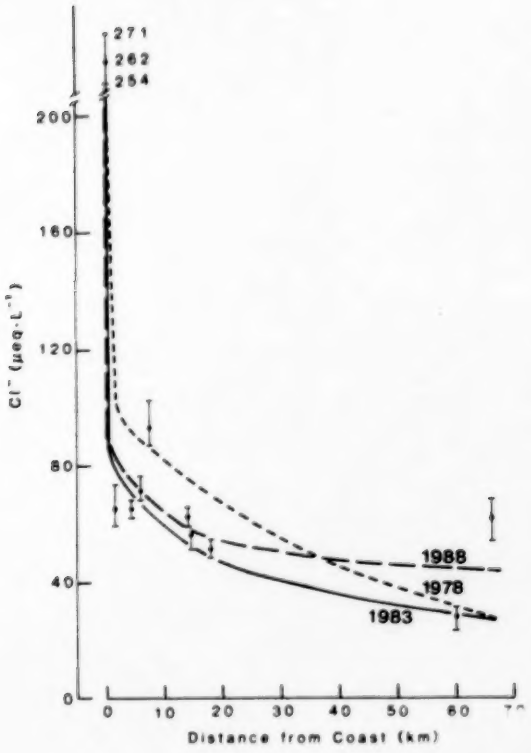

Fig. 9. Mean chloride concentrations in surface waters of the 10 study lakes from April-October in 1988 as related to distance from the coast compared to 1978 and 1983 levels.

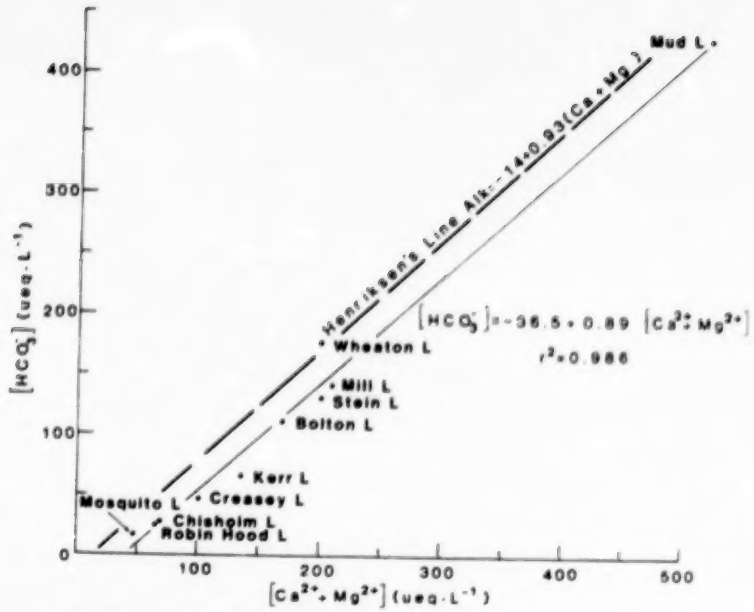

Fig. 10. The mean [Ca & Mg] sums plotted vs mean bicarbonate levels for the 10 N.B. lakes surveyed during the 1988 sampling season. The line fitting Henriksen's equation is also shown.

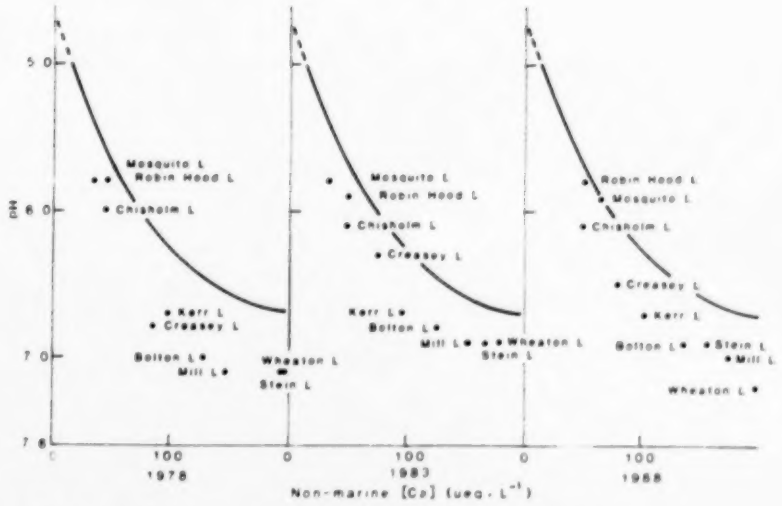

Fig. 11. Changes in non-marine Ca plotted vs pH over a 10-yr period. The mean points are shown in relation to the curve developed by Henriksen (1979) as an "acidification" indicator.

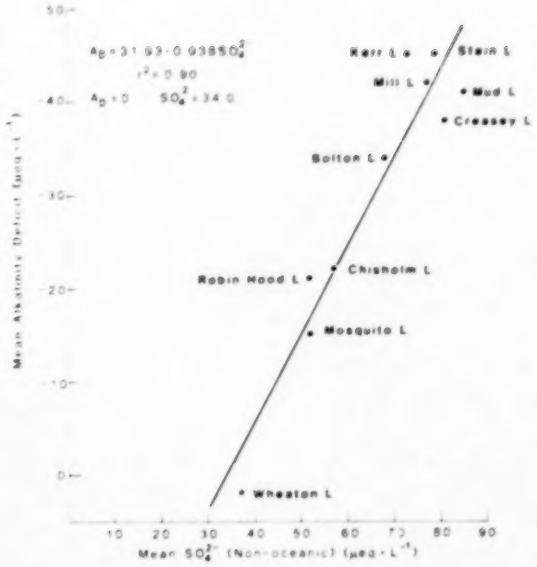

Fig. 12. The mean 1988 alkalinity deficits (A_D) are regressed on mean SO_4^{2-} concentrations for the 10 N.B. lakes surveyed.

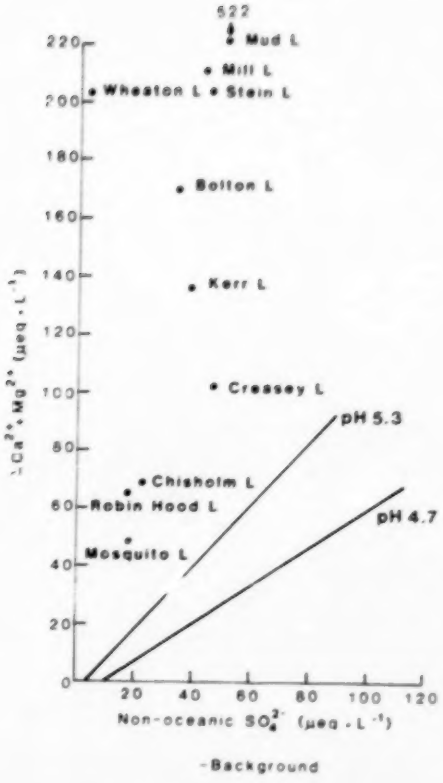

Fig. 13. For the 10 N.B. lakes Σ Ca & Mg are plotted vs the mean non-oceanic SO_4^{2-} concentrations minus "background" SO_4^{2-}.

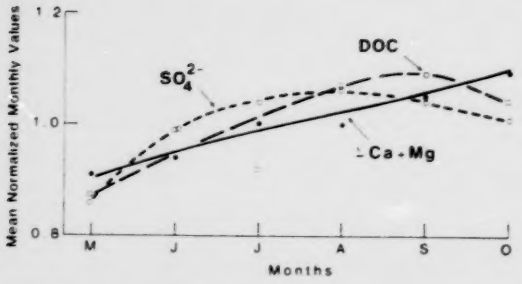

Fig. 14. Normalized monthly means plotted for Σ Ca & Mg, DOC and SO_4^{2-} for the lakes surveyed in 1988.

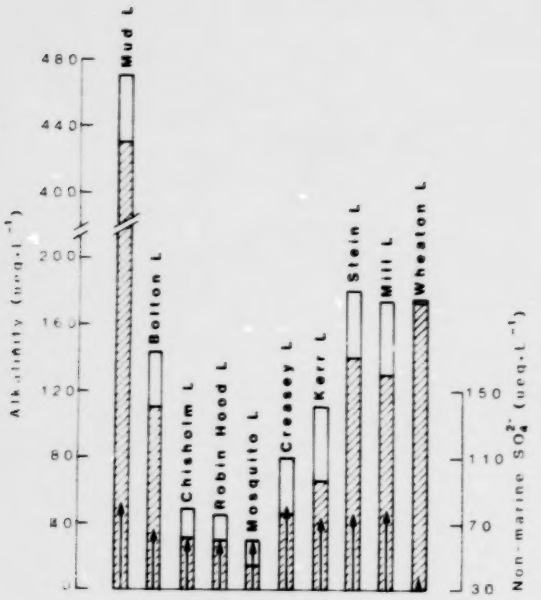

Fig. 15. Interrelationship of lake acidification and excess SO_4^{2-} in the waters of 10 N.B. lakes. Lake acidification is quantified by the alkalinity deficit which is the difference between the calculated "original" alkalinity (open bars) and the measured mean alkalinity (closed bars) in the various lakes. The arrows indicate the excess SO_4^{2-} present above the "background" of 30 μeq.L^{-1}.

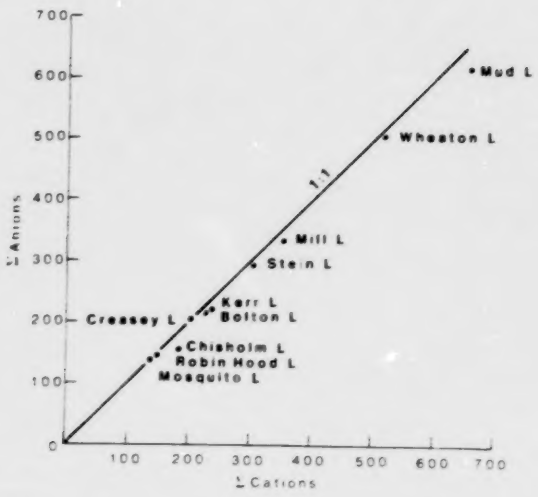

Fig. 16. Mean monthly ionic summations for each lake plotted with the 1:1 line to illustrate any deviations from cation and anion equality.

Appendix 1. Surface water temperature of the various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.
Mud	17.5	22.0	23.8	26.0	14.8	7.5
Bolton	15.0	17.5	24.0	27.5	16.8	8.5
Chisholm	15.0	19.0	22.5	26.0	14.0	5.5
Robin Hood	13.0	19.5	25.5	25.0	16.5	10.0
Mosquito	13.0	18.0	23.0	24.0	16.0	10.0
Creasey	14.0	21.0	23.0	27.5	16.0	9.0
Kerr	13.5	21.5	23.0	27.0	16.8	10.0
Mill	13.5	20.0	24.0	25.0	16.0	9.0
Stein	14.0	22.0	23.0	27.0	16.2	9.0
Wheaton	13.5	18.0	23.0	26.0	17.5	11.0

Appendix 2. Surface water conductivities ($\mu mho/cm^2$) of the various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.
Mud	51	45	69	73	56	48
Bolton	24	23	30	31	23	23
Chisholm	18	15	19	22	20	23
Robin Hood	19	15	24	20	23	38
Mosquito	20	19	20	19	20	27
Creasey	23	20	20	27	23	22
Kerr	22	15	29	29	25	31
Mill	32	33	40	45	32	38
Stein	30	29	36	33	28	30
Wheaton	45	48	59	62	50	50

Appendix 3. Sodium concentrations ($\mu eq.L^{-1}$) in surface waters of lakes, 1988. Sodium calculated to be of sea salt origin shown in parentheses. Total concentrations are the sum of the two figures.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	a	22 (48)	21 (53)	22 (56)	22 (56)	20 (58)	21
Bolton	28 (20)	24 (24)	19 (24)	24 (24)	21 (27)	24 (24)	23
Chisholm	17 (44)	22 (48)	19 (51)	19 (51)	30 (48)	25 (53)	22
Robin Hood	24 (41)	21 (44)	26 (44)	24 (46)	30 (44)	30 (44)	26
Mosquito	19 (51)	1 (51)	23 (51)	18 (56)	27 (51)	22 (56)	18
Creasey	18 (65)	25 (58)	25 (58)	22 (61)	25 (58)	22 (61)	23
Kerr	22 (56)	25 (53)	27 (56)	20 (58)	30 (53)	27 (56)	25
Mill	25 (75)	34 (75)	29 (80)	34 (83)	37 (80)	34 (88)	32
Stein	20 (63)	27 (51)	30 (53)	31 (56)	34 (53)	26 (61)	28
Wheaton	16(228)	21(218)	27(248)	23(225)	24(228)	23(233)	22
Mean normalized nonmarine Na	0.96	0.94	0.99	1.01	1.04	1.05	

[a]Anomalous value.

Appendix 4. Chloride concentrations ($\mu eq.L^{-1}$) in surface waters of various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	54	56	62	65	65	68	62
Bolton	23	28	28	28	31	28	28
Chisholm	51	56	59	59	56	62	57
Robin Hood	48	51	51	54	51	51	51
Mosquito	59	59	59	65	59	65	61
Creasey	76	68	68	71	68	71	70
Kerr	65	62	65	68	62	65	65
Mill	87	87	93	96	93	102	93
Stein	73	59	62	65	62	71	65
Wheaton	265	254	257	262	265	271	262

Appendix 5. Bicarbonate concentrations ($\mu eq.L^{-1}$) for the various lakes, 1988.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	307.7	365.6	419.6	491.5	499.5	497.5	430
Bolton	99.9	105.9	103.9	119.9	113.9	120.0	111
Chisholm	26	32	20	24	24	36	27
Robin Hood	18	26	18	42	22	28	26
Mosquito	18	16	18	14	12	16	16
Creasey	36	32	36	53.9	46	55.9	47
Kerr	59.9	61.9	63.9	67.9	69.9	77.9	67
Mill	107.9	121.9	133.9	175.8	145.8	158.0	141
Stein	107.9	141.9	121.9	141.9	117.9	152.0	131
Wheaton	159.8	165.8	163.8	191.8	177.8	201.8	177
Mean normalized HCO_3^-	0.86	0.95	0.90	1.12	0.97	1.14	

Appendix 6. Sulphate concentrations ($\mu eq.L^{-1}$) as determined by ion chromatography in surface waters of various lakes, 1988. Sulphate calculated to be of sea salt origin shown in parentheses. Total concentrations are the sum of the two figures.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	74 (5.4)	86 (5.6)	94 (6.2)	92 (6.5)	86 (6.5)	80 (6.8)	85
Bolton	60 (2.3)	66 (2.8)	70 (2.8)	72 (2.8)	70 (3.1)	70 (2.8)	68
Chisholm	43 (5.1)	52 (5.6)	61 (5.9)	61 (5.9)	61 (5.6)	65 (6.2)	57
Robin Hood	39 (4.8)	51 (5.1)	55 (5.1)	55 (5.4)	55 (5.1)	55 (5.1)	52
Mosquito	46 (5.9)	52 (5.9)	54 (5.9)	54 (6.5)	54 (5.9)	54 (6.5)	52
Creasey	71 (7.6)	78 (6.8)	80 (6.8)	85 (7.1)	83 (6.8)	87 (7.1)	81
Kerr	69 (6.5)	73 (6.2)	69 (6.5)	76 (6.8)	75 (6.2)	75 (6.5)	73
Mill	70 (8.7)	76 (8.7)	81 (9.3)	77 (9.6)	85 (9.3)	73(10.2)	77
Stein	76 (7.3)	77 (5.9)	81 (6.2)	81 (6.5)	81 (6.2)	78 (7.1)	79
Wheaton	29(26.5)	40(25.4)	39(25.7)	43(26.2)	39(26.5)	33(27.1)	37
Mean normalized SO_4^{2-}	0.86	0.99	1.04	1.06	1.04	1.01	

Appendix 7. Non-marine sulphate concentrations ($\mu eq.L^{-1}$) as determined by the colorimetric technique in surface waters of various lakes, 1988. Sulphate calculated to be of sea-salt origin is listed in appendix 6.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	80	90	96	93	91	95	91
Bolton	72	78	65	76	72	78	74
Chisholm	51	63	55	69	71	81	65
Robin Hood	63	68	54	59	72	72	65
Mosquito	53	59	50	56	50	64	55
Creasey	79	81	84	87	87	91	85
Kerr	77	88	75	85	77	87	81
Mill	82	93	85	92	91	88	89
Stein	86	94	84	93	92	95	91
Wheaton	37	48	35	45	40	44	41